10 kV at 10 km: Will it Fly?

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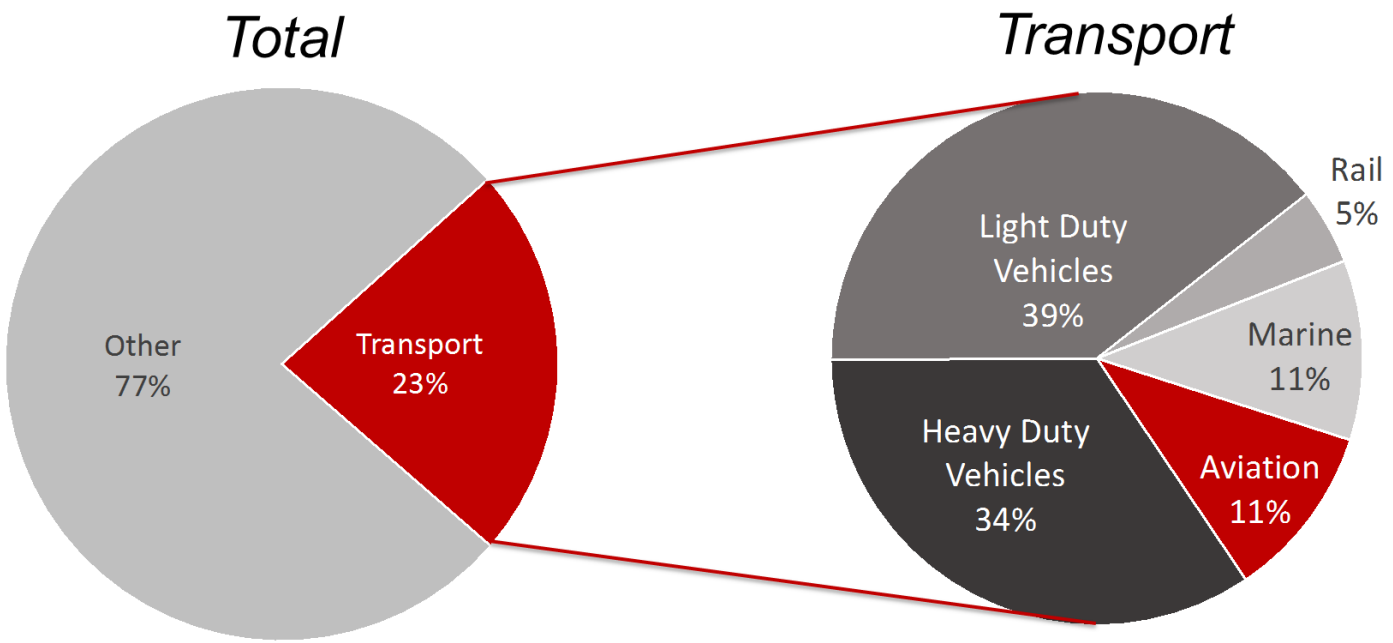
Global CO_2 Emissions: Aviation Difficult-to-Eliminate Emissions

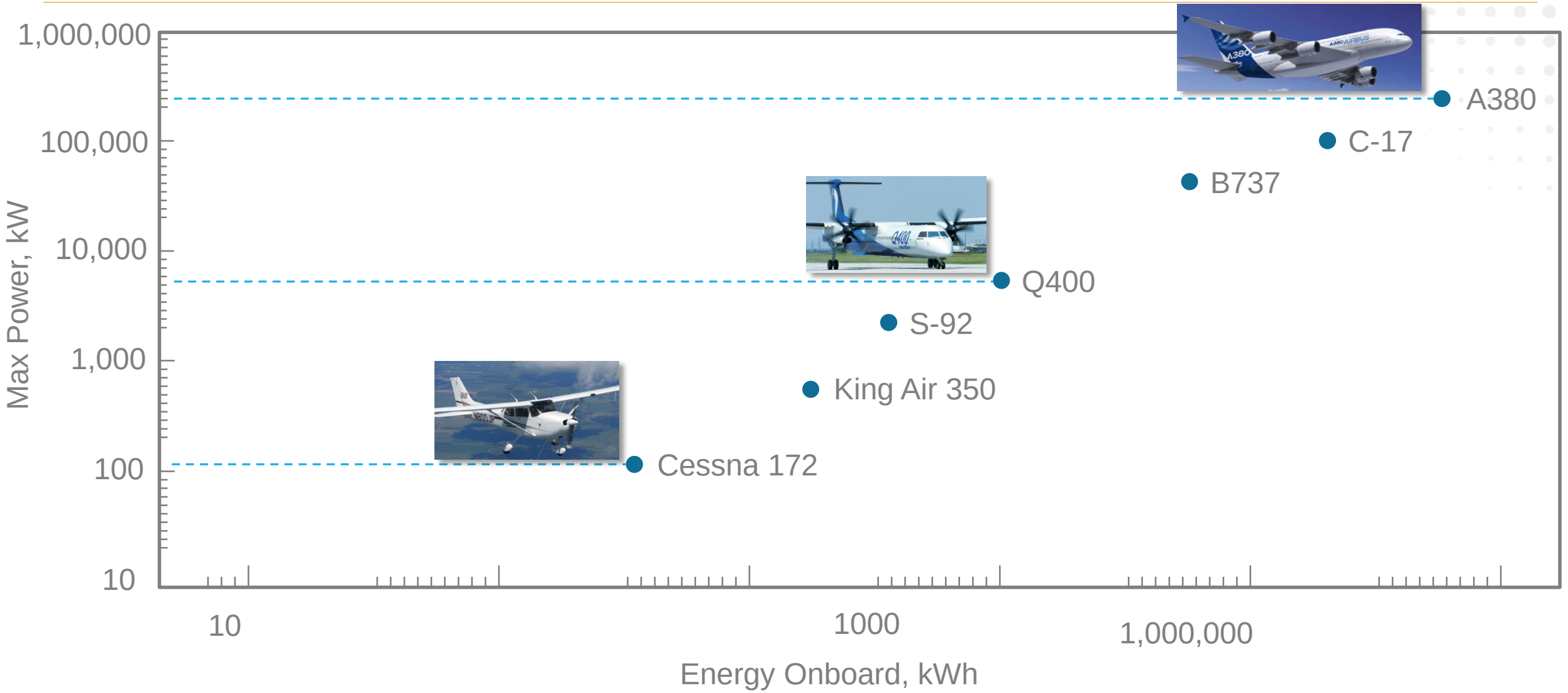


Technology needs:

1. Energy storage
2. Efficient, light weight & low cost
3. **Cabling & electrical conversion**

2014 data | Reference: https://www.theicct.org/blogs/staff/a-world-of-thoughts-on-phase-2

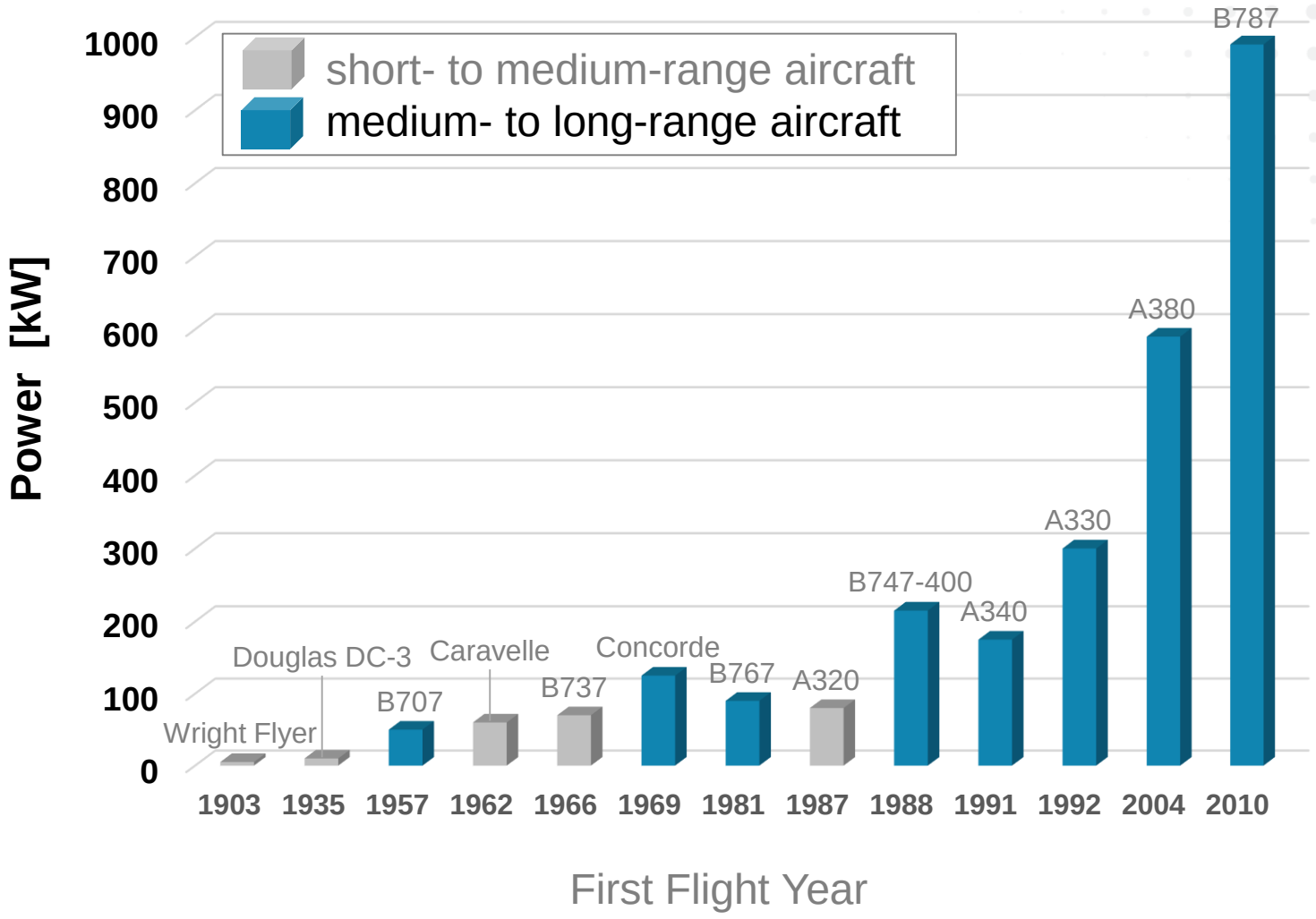
Large electric aircraft will require “utility-scale” power at take off



Source: National Academies of Sciences, Engineering, and Medicine. 2016. *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*. Washington, DC: The National Academies Press.

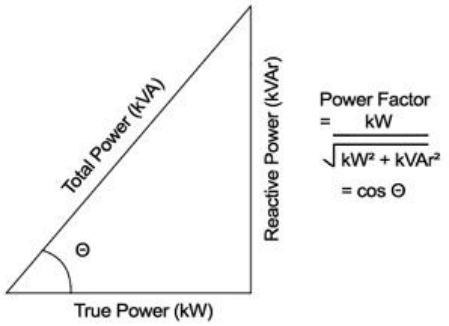
Today, onboard electrical power is orders of magnitude lower

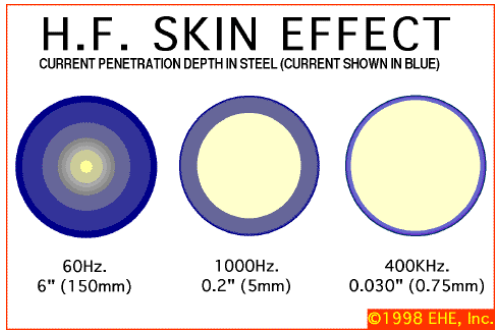
- Today's **maximum electric generation** capacity:
  1 MW (B787)
  - Ancillary power (e.g. HVAC, avionics, actuators, de-icing)
  - 500 km of wiring
  - 7,400 kg
  - 235 V_{AC}
- Fully **electric propulsion will require 100x** power



https://aerospaceamerica.aiaa.org/features/war-on-wiring/
V. Madonna, P. Giangrande and M. Galea, "Electrical Power Generation in Aircraft: Review, Challenges, and Opportunities," in IEEE Transactions on Transportation Electrification, vol. 4, no. 3, pp. 646-659, Sept. 2018. doi: 10.1109/TTE.2018.2834142

DC Offers Greater Efficiency and Power than AC



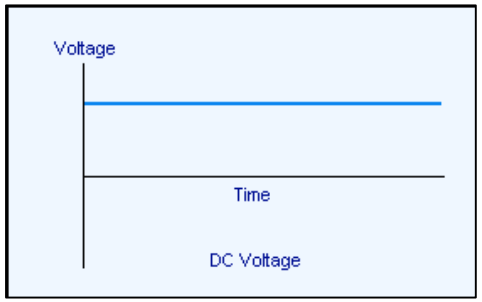


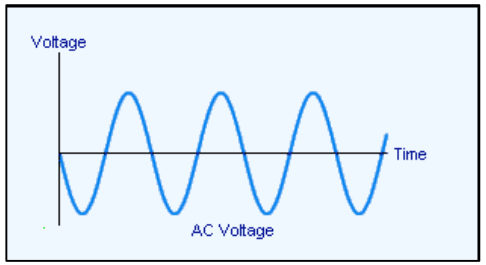
Benefits

- Reduced losses
- Fewer cables
- Less weight
- Increased payload

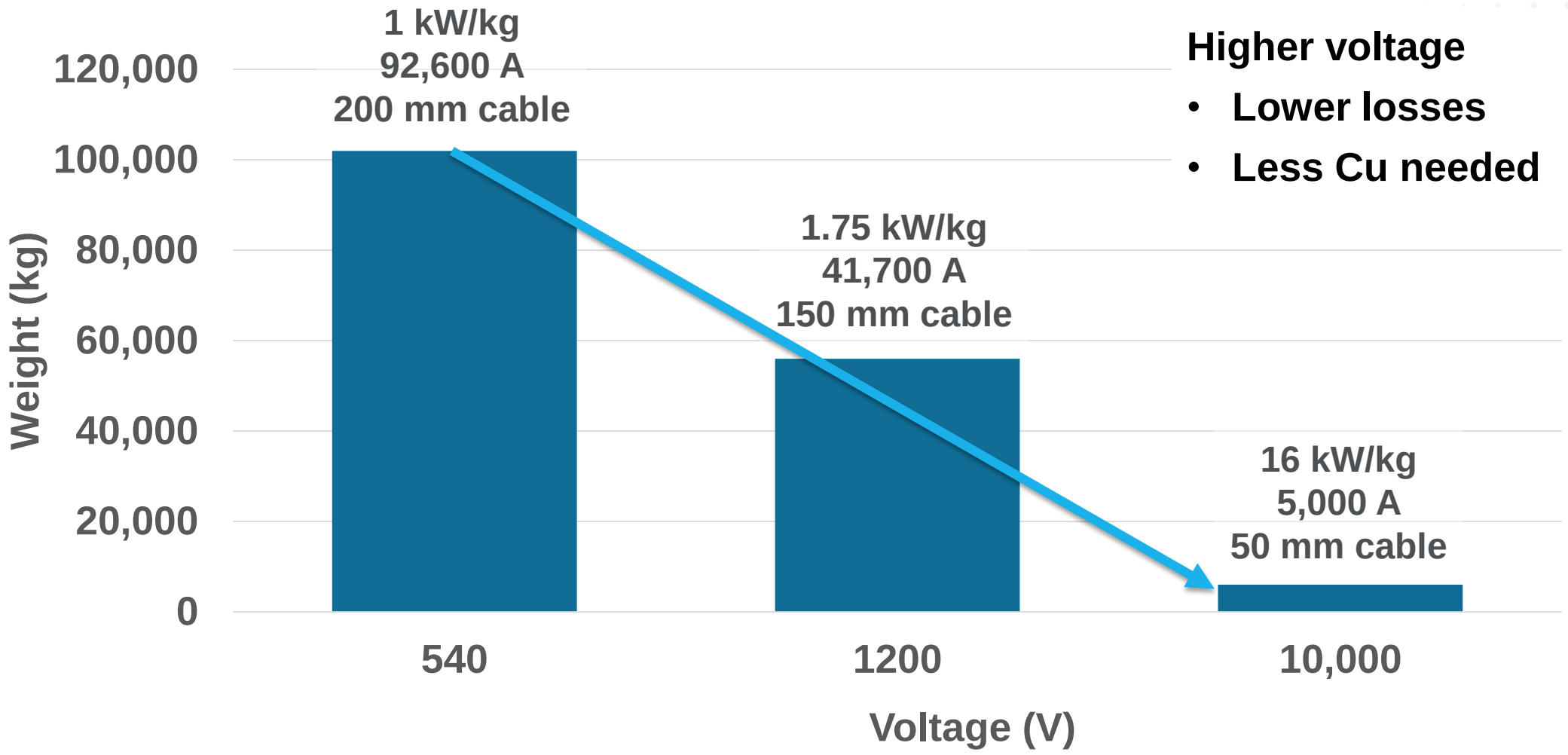
Challenges

- Asset protection
- More power electronics



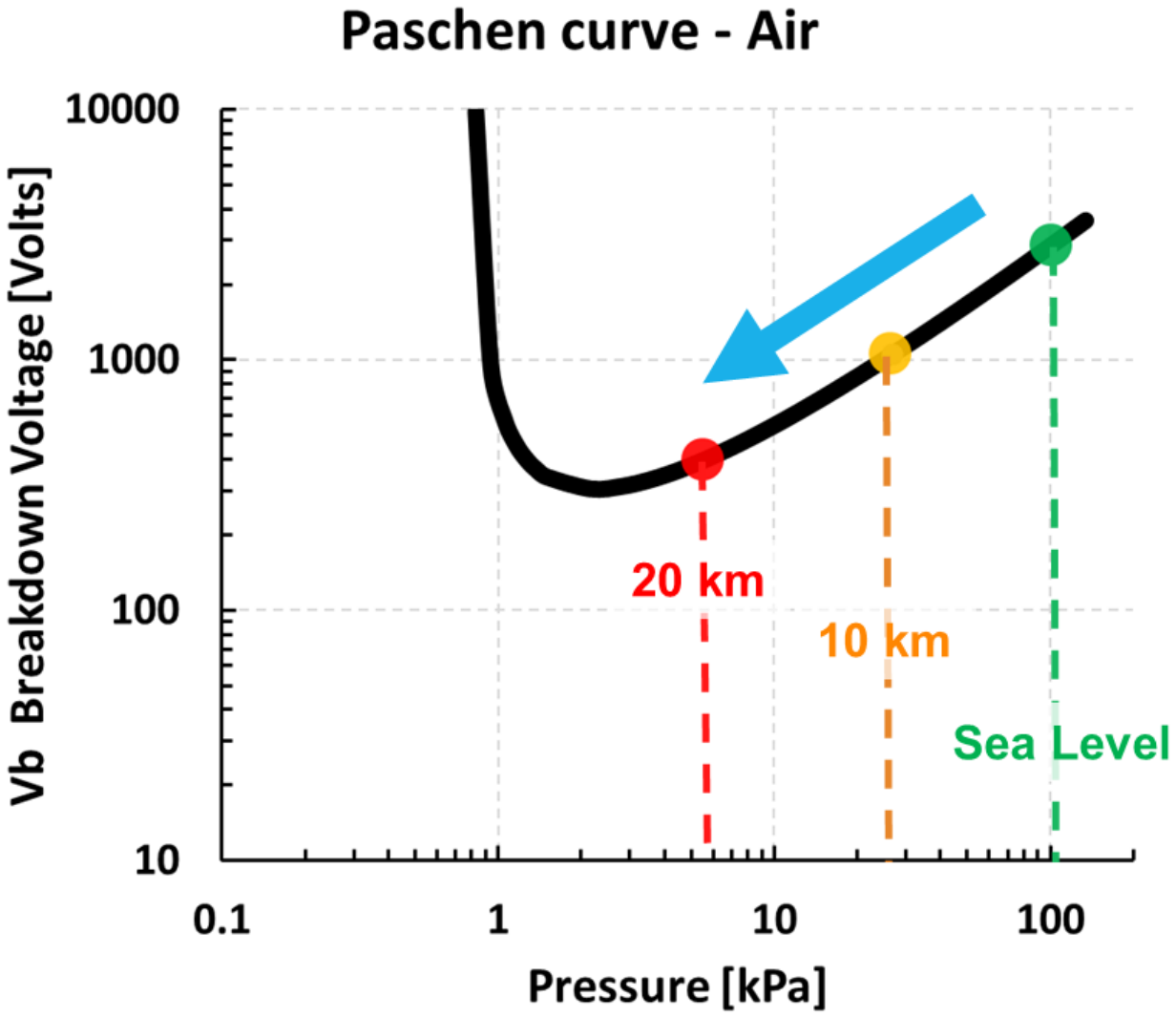


High voltages and lower current reduce cable weight…



* Weight estimated for 8, 45 m cables; conductor weight only, insulation will add additional weight
* Assumed 50MW cable, 100MW aircraft, 2X redundancy, 2 generators
*Cu conductor, area change due to thermal expansion <0.5%

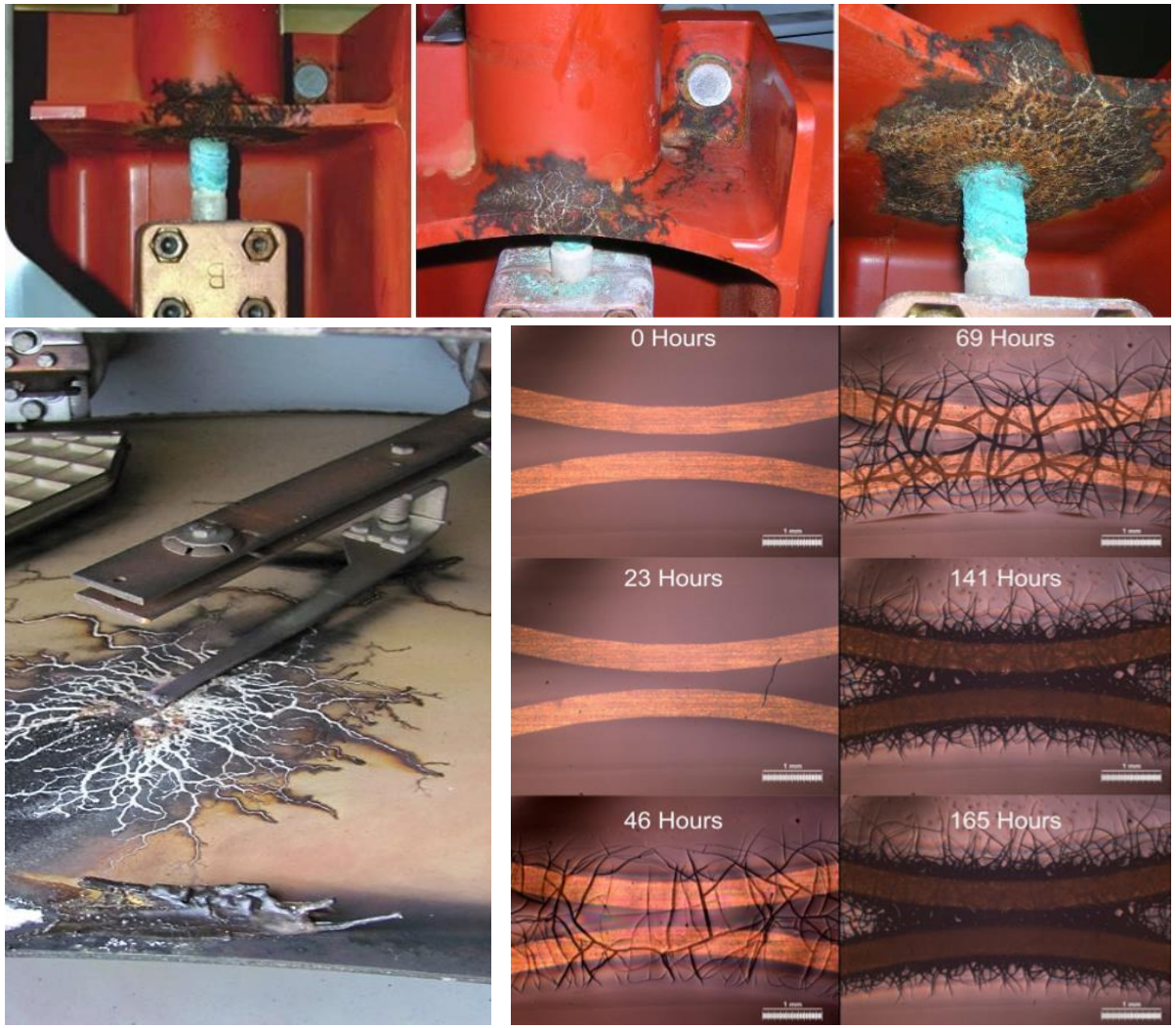
…but high voltages at low pressures creates discharge!



- Partial discharge
  - High electric fields
  - Breakdown of gases
  - Electrodes not bridged
  - V_b is 3X lower at 10km
- Bubbles in liquids
- Voids in dielectrics
- High-frequency breakdown
- Temperature effects

* Assumed 500-µm gap
* Assume U.S. Standard Atmosphere

Partial discharge can lead to complete failure

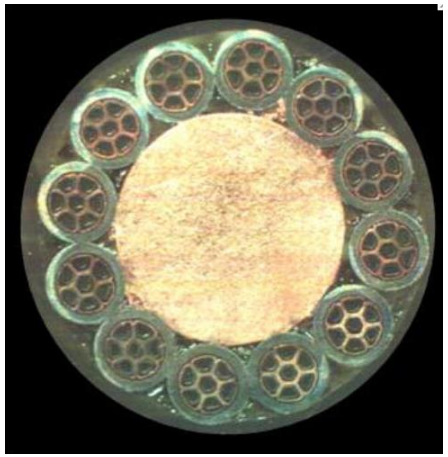


- Frequent discharge events can lead to irreversible damage
- Chemical transformation can accelerate the breakdown process

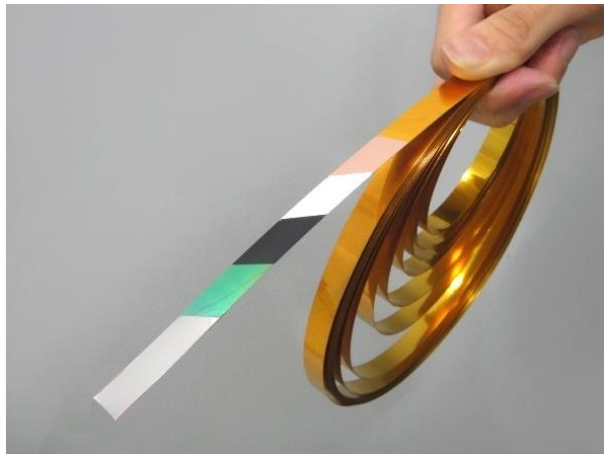
Insulation material innovations need to meet challenging targets

https://www.ecmweb.com/test-measurement/partial-discharge-and-asset-management
https://www.eatechnology.com/wp-content/uploads/2017/10/Testing-Distribution-Switchgear-for-Partial-Discharge-2008.pdf,
Emersic, C., Lowndes, R., Cotton, I., & Rowland, S. (2017). The Effects of Pressure and Temperature on Partial Discharge Degradation of Silicone Conformal Coatings. IEEE Transactions on Dielectrics and Electrical Insulation, 24(5), 2986-2994. https://doi.org/10.1109/TDEI.2017.006466

Possible Solutions



MgB_2 super-cooled to 25 K, liquid H_2



YBCO super-cooled to 77 K, liquid N_2

Nexans high voltage transmission cable

Superconducting Systems:

- Able to withstand high currents with minimal losses
- Wires and cooling system ~60,000 kg
- Cryogenic system reliability, efficiency and weight are critical

Insulating materials:

- Need dielectric strength, good thermal conductivity, and low specific weight
- Conformal, easily shaped
- Minimize voids

https://www.fujikura.co.uk/products/energy-and-environment/2g-ybco-high-tempurature-superconductors/
http://www.hypertechresearch.com/mgb2%20wire.htm
https://www.researchgate.net/publication/230926720_MgB2_bulk_and_tapes_prepared_by_mechanical_alloying_Influence_of_the_boron_precursor_powder
https://www.nexans.de/eservice/Germany-en/navigatepub_148784_-4792/Nexans_wins_a_73_million_Euro_contract_in_den_Unit.html

We want your input!

- What does electrical distribution topology need to look like?
- Is superconducting wire the only viable approach?
- What do we need from power converters?
- How about the electrical connector technology?
- What innovation is needed for insulation materials?
- Do we have scalable manufacturing processes?

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